Clonal Oil Palm: Production, Yield Performance and Nutritional Requirements

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INTRODUCTION

The theoretical **potential yield** in oil palm is the maximum oil yield that can be obtained by the crop as determined by simulation models (Evans and Fischer,1999) . In oil palm the potential yield has been estimated at up to 17 t ha^{-1} (Breure, this volume, Corley, 1985), more than four times present recorded average oil yields in Malaysia of about 3.6 t ha^{-1} and 2.4 to 3.4 times greater than reported oil yields of 5–7 t ha^{-1} in some well managed plantations.

The **yield potential** is defined as the yield of a cultivar, adapted to the environment in which it is planted, with an adequate supply of nutrients and water with no pest and disease stresses (Evans and Fisher, 1999). Aside from constraints to the expression of the yield potential of currently available planting materials, such as planting on unsuitable areas (Paramanathan, this volume) and inadequate agronomic management (Fairhurst *et al*., this volume), present yield gaps are partly explained by the limited yield potential of currently used hybrid F1 seed of conventional Tenera (Dura x Pisifera, D x P) planting materials. Ng *et al*. (1999) suggested that the quantum leap required to reach the theoretical potential yield of oil palm can only be achieved by using tissue culture via somatic embryogenesis to clone very high yielding palms for commercial planting.

Attempts to propagate the oil palm through tissue culture methods began in the early 1960s (Rabechault, 1962; Bouvinet and Rabechault, 1965; Buffard-Morel, 1968; Rabechault and Ahee, 1966; and Rabechault *et al*., 1968; 1969). At the outset, the work focused on the use of zygotic embryogenesis with seed embryos to obtain calli and plantlets. This route was favored by many workers in Malaysia because of the high incidence of abnormalities detected in ramets derived from both root and leaf explants obtained from seedlings as well as selected ortet palms. Other palm parts and organs were used by some workers, including stem apices (Rabechault *et al*., 1972 ; Staritsky, 1970), and root tissue (Martin *et al*., 1972; Smith and Thomas, 1973; Ong, 1975; Corley *et al*., 1977; 1979), and some complete plantlets were planted commercially (Corley *et al*.,1977; 1979; 1982). Inflorescence culture has also been used to regenerate plantlets.

More recently, the use of small leaf fragments from immature leaves as explants has again become the favored approach (Pannetier *et al*., 1981; Noiret, 1981; Lioret, 1982; Duval *et al*., 1988; Agrocom, 1993). Somatic embryogenesis using leaf explants has been found to give consistent results and improvements in tissue culture protocols and techniques have reduced or eliminated the occurrence of abnormalities.

Large scale commercial planting of clonal oil palm in plantations was limited mainly by the unacceptably high incidence of floral abnormalities, especially the 'mantled fruit' trait. More recent work by Khaw and Ng (1998), and Khaw *et al.* (1999), however, show that this problem can be minimized, and since 1989 more than 4,000 hectares of commercial clonal oil palm plantings have been established that consistently out-yield conventional D x P plantings by more than 30% (Agrocom, 1995).

This chapter reviews the rationale for cultivating clonal oil palms produced from tissue culture, introduces the criteria used to select ortet palms and outlines the basic principles of *in vitro* culture. The yield performance and nutrient dynamics of clonal oil palms is compared with conventional seed planting material (D x P).

RATIONALE FOR CULTIVATING TISSUE CULTURED (CLONAL) OIL PALM

The fruit bunch or oil yield of a population of oil palms in a small plot, single field, or plantation, is the sum of the yields of individual palms that make up the population. Even in a uniform environment, a stand of D x P material derived from seed will tend to exhibit considerable palm to palm variation in vegetative growth characteristics and yield performance, and the amount of variability depends on seed origin and nursery selection practices. Thus, the yield potential is always limited by the performance of the poorest palms and the proportion of the total stand made up of such palms. Unfortunately, high yielding palms are always in the minority in a population of palms in a commercial planting, even where high standards of nursery culling are practised (Gillbanks, this volume).

With the introduction of high yielding clonal planting materials that are much more uniform in both genotype (within a clone) and phenotype, two important aims are achieved (Figure 1):

- The yield is more uniform amongst members of a population of clonal palms (i.e. a smaller variation around the mean yield); and

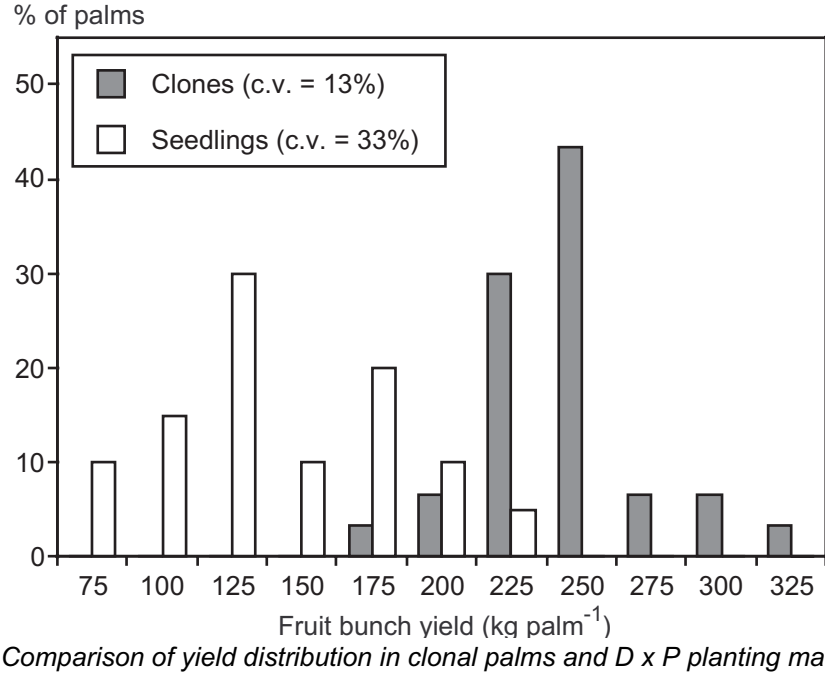

Figure 1. Comparison of yield distribution in clonal palms and D x P planting materials.

- There is a significant shift to the right of the peak in the yield distribution.

Ooi *et al*., (1995) compared the fruit bunch yield distribution of clonal palms with that of seedling (D x P) palms and showed that the yield of the majority of clonal palms peaked close to the population mean (coefficient of variation = 13%), whereas in the seedling D x P population yields were more widely distributed over several yield classes (coefficient of variation = 33%) (Figure 1). In addition, the mean fruit bunch yield of the clonal palms was more than 231 kg palm^{-1} compared to 130 kg palm^{-1} in the D x P population (Figure 1). About 73% of palms in the clonal population yielded between 200–250 kg palm^{-1} fruit bunches whereas in the D x P population only 40% of palms produced bunch yields of between 100–150 kg palm^{-1}.

SELECTION OF ORTET PALMS

The selection of ortets (i.e. selected mature palms used as a source of explants for cloning) is a crucial step in a clonal oil palm production program since the yield of each clone is the same as the yield of the ortet from which it has been cloned. Thus, the selection process must be rigorous, and only elite palms, in terms of fruit bunch and oil yield and other important characteristics, should be selected for cloning.

Hardon *et al*. (1987) and Meunier *et al*. (1990) performed various assessments of the potential to increase productivity using clones and predicted a yield improvement of 30%. Corley (1993) estimated that selecting the best 2% of palms in a population would give an expected average yield increase of 24%, whereas Soh (1986) estimated that cloning the best 5% of ortets selected for oil yield over three to seven years, would give an average yield improvement of only 12%, and suggested that selection of the best families followed by selection of the best individuals within those families would result in greater increases in productivity than selection of individuals without regard to family.

Soh and Chow (1989) also asserted that selection for a combination of yield components would be more efficient than direct selection for oil yield alone. However, Baudouin and Durand-Gasselin (1993) showed that bunch production and quality were much more heritable than previous estimates had suggested, and indicated that selection for oil yield would be worthwhile. This was the strategy we adopted in the late 1970s to select ortets for cloning (Agrocom, 1993). Our ortet selection criteria was reported by Ooi *et al*. (1995) and ortets were selected for:

- combination of high oil content (>28% oil to bunch) and large bunch yield (>200 kg palm^{-1} yr^{-1}),
- precocity (immaturity period of ~2 years),
- low height increment (< 45 cm yr^{-1}) (Figure 2), and

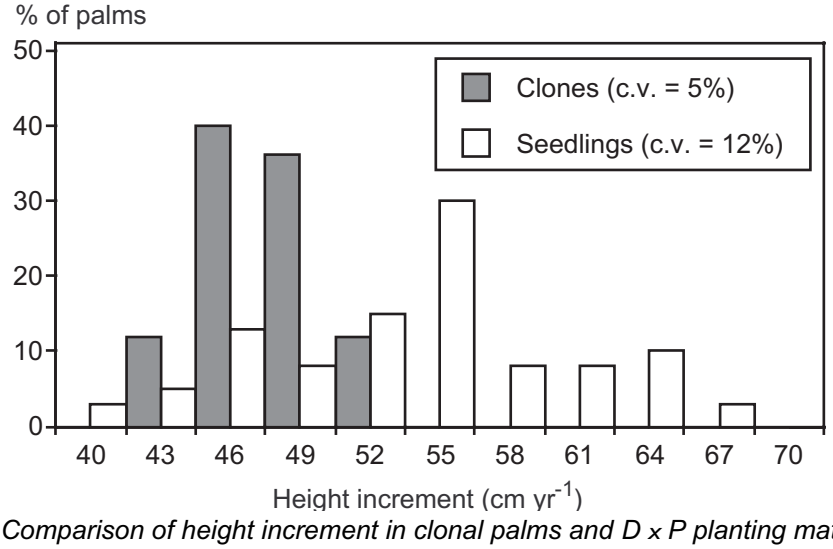

Figure 2. Comparison of height increment in clonal palms and D x P planting materials.

- secondary characters (e.g. bunches with short spines).

The success of this selection methodology has been demonstrated in field trials where fruit bunch yield was increased by 20–40% and oil yield by >30% when clones were compared with D x P material (see Table 3 and 4). Less than 2% abnormal palms were detected in clonal palms produced when these selection criteria were used in combination with suitable laboratory techniques (see Table 2).

THE TISSUE CULTURE PROCESS FOR LEAF FRAGMENTS

After decontamination, laminae from un-emerged spear leaves are cut into approximately 1 cm^2 fragments and incubated on culture media containing auxin to promote callus induction. Callus yield from explants can vary between 20–70% (Lioret, 1982), and typical yields of 25–30% were reported for some crosses (e.g. Deli x La Mé). Much smaller callus yields of 5–10% were reported by Duval *et al*. (1988) for Deli x Yangambi material and 5–20% for Yangambi material (Ginting *et al*., 1993). Callus yields of 20–60% after 3–5 months were reported by (Ginting *et al*., 1993) for material of La Mé origin.

Calli can be observed from as early as two months but more usually 4–6 months after the start of incubation. Light is not required in this first phase. Callus material is then re-cultured on media containing either auxin, cytokinin or a combination of both hormones to induce embryogenesis. The first embryoids are formed after about four months, and production continues for about twelve months. Embryoids are subsequently transferred to a proliferation media to induce secondary embryogenesis (Duval *et al.*, 1988).

Direct embryogenesis (i.e. embryoids form directly on the leaf fragments without going through a callus phase, as used in the propagation of plants such as Begonia) occurs only rarely on leaf fragments. The embryoids germinate into shoots which, when large enough, are transferred to a rooting medium.

The auxins used in leaf fragment culture for callus induction include 2,4-D or 2,4,5-T (Rabechault and Martin, 1976), or NAA (Paranjothy and Othman, 1982). For embryogenesis and shoot production, a combination of auxin (NAA, IBA) and cytokinins (Kinetin, BA, 2-IP) are used (Rabechault and Martin, 1976; Paranjothy and Othman, 1982). For rooting, either NAA or IBA or NAA and IBA in combination with GA3 have been used (Staritsky, 1970; Rabechault and Martin, 1976; Paranjothy and Othman, 1982; Nwankwo and Krikorian, 1983; Thomas and Rao, 1985).

The next stage is the acclimatization of plantlets (that already have shoots and roots) in a weaning nursery. The total duration of the process from harvesting explants to field planting takes about 60 months (Table 1).

Table 1. Time-frame for producing clonal plantlets ready for field planting.

Process	Duration
Harvesting explants, disinfection and inoculation	1 - 4 days
Callus initiation	3 - 6 months
Embryogenisis	6 - 15 months
Embroid proliferation and shoot production	24 months
Plantlet development	30 months
Rooting	36 months
Weaning and hardening	40 months
Main nursery	48 months
Field planting	60 months

CONSTRAINTS ON THE LARGE SCALE INTRODUCTION OF CLONAL PALMS

A major constraint on the cultivation of clonal palms on a commercial scale has been the occurrence of abnormalities (Corley, 1986). A major form of abnormality in clonal palms arises from the abnormal development of the androecium in male and female inflorescences. In the case of the female inflorescence, one to six of the normally vestigial stamens or staminodes in a female flower may develop into a mantle of fleshy carpel-like structures surrounding the fruit, resulting in what is now known as 'mantled fruit'. Such mantled fruits are usually parthenocarpic (i.e. the fruits are formed without fertilization), though not always, and bunches with a high proportion of these fruits fail to ripen, resulting in bunch failure. On male flowers, each of the six stamens may similarly develop into fleshy carpel-like structures. When male flowers on a palm are mantled, the female flowers are also always severely mantled (Durand-Gasselin *et al*., 1995).

Another common but less serious form of abnormality occurs in the male inflorescence. Some or all of the individual flowers develop into female instead of male flowers and small parthenocarpic fruits may be formed. This type of abnormality, referred to as androgynous development of the male inflorescence is, however, not unique to clonal palms, and is common in young D x P seedlings at the onset of flowering, though the condition usually disappears before the onset of harvest. In clonal palms, however, some or most of the female flowers in an androgynous male inflorescence may also be mantled. Whether or not clonal palms with mantled fruit and/or flowers revert to normal growth depends on the severity of the abnormality. Both partially and fully mantled palms have been found to revert to normal growth three or more years after field planting.

Parthenocarpic fruit formation is also common in young clonal palms, but this abnormality does not persist in the field. Parthenocarpy also occurs in normal D x P palms if palms are contaminated when the palm circles are sprayed with herbicides containing phytohormones (e.g. 2,4-D, dicamba and picloram) (Khairudin and Teoh, 1988).

A number of reports have documented the incidence of abnormalities in clonal palms. Of the three clones planted in Unipamol Estate, both male and female inflorescences in the three clones were normal in the 1981 plantings, but abnormalities were evident in the 1982 (25%) and 1983 (88–95%) plantings (Corley *et al*., 1986). Out of 93 La Mé clones, 49 clones were abnormal (53%) and the level of abnormality ranged from <25–62%, while 19 clones had abnormality levels of >5% (Durand-Gasselin *et al*., 1995). Maheran *et al*. (1995) reported an average of 4.2% abnormal palms in clones of La Mé origin that were slightly to severely mantled. They also reported that 62% of mantled palms reverted to normal growth three years after planting (YAP). The authors found that clones with normal appearance *in vitro* and in the nursery usually presented very low levels of abnormality (about 2%) in the field. Khaw and Ng (1998), monitored their clones planted under commercial conditions over a period of five years, and reported that the incidence of mantled palms in mature stands was less than 1% (Table 2).

POSSIBLE CAUSES OF ABNORMALITIES IN PALMS

In various studies the chromosome number was found to be the same in abnormal and normal clonal palms (Corley *et al*., 1986; Soh, 1987; PORIM, 1988). Furthermore, DNA molecular analysis using restriction fragment length polymorphisms (RFLPs) failed to reveal differences between normal and abnormal palms (Cheah *et al*., 1989). Similarly, no differences in isoenzyme profiles have been detected, however, when normal and abnormal palms were compared.

The fact that abnormal palms, whether partially or fully mantled, have been observed to revert to normal after more than three years in the field lends support to the suggestion that it is primarily an internal regulation problem (Duval *et al*., 1995) and possibly epigenetic (Paranjothy *et al*., 1995). Epigenetic changes are stable but potentially

Table 2. Census of abnormal (mantled) palms of AGK clones from Agrocom, planted from 1988–1993 (Khaw and Ng, 1997).

Location	Date of planting	Number of palms counted at maturity	Number of mantled palms	Mantled palms %
Peninsular Malaysia	1988	108	0	0
	1989	780	2	0.25
	1990	753	5	0.66
	1991	885	18	2.03
	1992	2,945	41	1.39
	1993	577	6	1.04
Sabah	1991	284	4	1.41
	1992	6,231	11	0.18
Sarawak	1992	57	0	0
Total	-	12,620	87	0.70

reversible modifications in the expression of genes, but are not usually transmissible by meiosis.

Views differ with regard to whether the mantled fruit abnormality persists in seedlings derived from affected bunches. Rao and Donough (1990) detected the abnormality in seedlings derived from mantled fruits, raising the possibility that abnormalities could be carried on DNA and transmitted during meiosis. On the other hand, spontaneous reversion to normal growth has been reported for affected seedlings established from mantled fruit (Donough, 1990). Clearly, the question of meiotic transmission of abnormal traits needs further investigation. Random amplified polymorphic DNA (RAPD) and RFLP studies have so far failed to detect polymorphism in DNA between normal and abnormal ramets (Rival, *et al*., 1998).

Corley *et al*. (1986) suggested that prolonged culture on media containing large concentrations of plant hormones may cause floral abnormalities. Rapid sub-culture of polyembryogenic cultures on media containing growth promoting substances has also been implicated causally and this has, to some extent, been shown by Duval *et al*. (1988) who reported that no abnormalities were detected in cultures maintained on basal media free of hormones.

Paranjothy *et al*., (1995) examined the incidence of abnormalities in relation to subculture in clones produced at PORIM and Applied Agriculture Research Sdn. Bhd., (AAR) and found that in four PORIM clones derived from polyembrionic cultures maintained on media containing auxin and cytokinin, the incidence of abnormalities increased rapidly from the sixth subculture. In PORIM clones P8 and P13 the incidence of abnormalities was 25% and 50% by the ninth and eighth subculture, respectively, whilst in clones P10 and P15, the incidence was 68% and 50% respectively by the tenth culture. In the AAR clones derived from polyembrionic cultures maintained on media containing auxin only, the incidence of abnormalities also increased with the number of subcultures, but the level did not exceed 5% even by the 25th subculture. It was noted, however, that the number of shoots produced was reduced at each subculture in the AAR clones.

The type of callus used for somatic embryogenesis also affects the frequency of the mantled fruit trait. Duval *et al*. (1988) showed that embryoids derived from nodular calli resulted in 5–10% abnormal palms, whereas embryoids obtained from friable fast-growing calli gave 100% abnormal palms. Compared to nodular calli, fast-growing calli from the same ortet were found to have a much higher ratio of auxin: cytokinin. Duval

et al. (1995) reported that nodular callus could be converted to fast growing callus in the presence of high levels of 2,4-D while Lo Schiavo *et al*., (1989) showed that 2,4-D increases the level of DNA methylation in carrot cell cultures. These findings suggest that hypermethylation of DNA induced by 2,4-D could be linked to the development of abnormalities. However, this is just one of many other proposed causes (including transposon mediated mutations, DNA amplification, changes in organelle DNA, and high frequency site-specific mutations or recombinations) that could account for the main features of the mantled fruit abnormalities, namely high incidence, meiotic transmission, and reversion (Paranjothy, 1993). Research in this field continues to be pursued vigorously.

Due to the difficulties reported in large-scale propagation of oil palm by tissue culture, alternative methods or strategies for the use of clonal propagation were suggested by Soh (1986, 1987) and PORIM (1988):

- Cloning of parents of the best D x P cross to produce bi-clonal F1 seeds. Up to the present, there have been no reports of bi-clonal seed production and, in any case, abnormalities may also occur when the Dura or Pisifera parents are cloned. Furthermore, normal selection procedures must be carried out, and many years of testing are needed before bi-clonal seeds can be introduced for commercial planting.
- Cloning the seedlings (or embryos) of elite D x P crosses. This approach, especially the embryo route, has been followed by a number of workers but may lead to unexpected results (e.g. cloning of Dura embryos due to pollen adulteration at fertilization).
- Avoiding the callus phase by direct embryogenesis (but this occurs only rarely)
- Limiting the number of sub-cultures to as few as possible (<15) and the use of shoot apex culture.
- Limiting proliferation per clone and developing protocols that reduce endogenous hormone build-up. Possible use of isoenzyme screening techniques (but until now isoenzyme analysis has not detected any difference between normal and abnormal shoots of a clone).

PRODUCTIVITY AND ECONOMICS OF CLONAL PALMS

Ginting *et al*. (1993) reported that a selection of clones, planted on an area of 99 ha, could be harvested 24 months after field planting. The reported fruit bunch production for the first two years was 29% greater than in conventional D x P palms. The vegetative characters of the clones showed greater homogeneity with narrow leaf pinnae and a lower leaf area index (*L*) than D x P material. Clones produced 11.3 and 13.0 tonnes ha^{-1} fruit bunch compared to 8.7 and 10.2 tonnes ha^{-1} for D x P palms in the first and second year of harvesting respectively in trials in Felda (Maheran *et al*., 1995). Overall, these trials showed an average increase of 30% both in fruit bunch and oil yields compared to conventional D x P material.

The early performance of oil palm clones in terms of bunch yield, oil to bunch (O:B) and oil yield from various sources (IRHO, PORIM and HRU/AAR) and from different locations in Malaysia, was reviewed by Soh *et al*. (1995). Of eight IRHO clones tested in Teluk Intan, the only clone to out-yield D x P material was LMC 088 (14% increase). None of the PORIM clones performed better in terms of bunch yield or oil yield than D x P controls at any of the locations, but clones P10, P30, P35, P40, P41 and P44 performed equally well when compared with the D x P control. This is to be expected as the PORIM clones were produced from unselected seedlings.

The PORIM/HRU clone P12 performed better than D x P, but the yield increases of 4% and 8% at two sites were very small. There was no difference between HRU/AAR clone 208 and D x P controls at any of the sites planted. Similar observations were made by Donough and Lee (1995), both for coastal and inland soils in Malaysia. Fruit bunch and oil yield of their best clones were not greater than the D x P control, except for a clone planted on a coastal soil, where oil yields of two clones were 11.4% and 15.7% greater than the D x P control.

Table 3. Fruit bunch yield for clonal and D x P palms on three different soil types in Peninsular Malaysia (Khaw and Ng, 1998).

Soil type	Planting material	25 - 36	37 - 48	49 - 60	61 - 72	73 - 84	85 - 96
Carey Series	AGK1*	20.4	31.6	40.2	43.9	40.6	-
	AGK6	20.6	32.0	40.1	40.0	50.2	-
	AGK8	17.8	27.3	39.0	37.5	39.5	-
	DxP control	11.3	24.0	30.4	34.6	34.5	-
Bukit Lunchu Series	AGK1	5.5	21.8	28.9	28.1	30.7	26.3
	AGK8	2.2	18.9	26.1	36.1	24.9	21.0
	DxP control	4.6	12.5	23.0	23.9	22.2	21.0
Bungor Series	AGK1	17.1	28.7	36.4	28.9	27.0	-
	AGK6	20.5	21.5	34.8	34.8	28.7	-
	AGK8	18.7	24.8	34.8	35.8	33.0	-
	DxP control	10.2	18.5	24.2	26.5	24.6	-

**AGK = clones of Agrocom Sdn. Bhd.*

The relatively poor performance of clones in the reported trial results above may be explained by the sub-optimal ortet selection procedures used that included the selection of untested seedlings instead of mature palms.

By contrast, Khaw and Ng (1998), following strict ortet selection procedures, as described earlier, found that yields in their clones were significantly greater than that of the D x P controls (Table 3).

The yields recorded were from pioneer plots of about 4 ha, and plantation management was based on standard commercial practices. In a more recent maximum yield trial, the genetic potential of a single clone was tested on a Merit Series soil (Typic Kandiudult) on an area of 0.42 ha in Sarawak (Khaw *et al*., 1999). The data from seven years of recording show that a maximum fruit bunch yield of 60.38 t ha^{-1} was achieved at 8 YAP and the sustained average yield from the third to ninth YAP was 50.16 t ha^{-1}. This corresponds to oil yields (based on a milling test of clonal fruit bunches) of 15.7 t ha^{-1} crude palm oil (CPO) at peak yield and 12.5 t ha^{-1} for the six years from four YAP. The corresponding yields of the D x P control were between 35–53% for fruit bunch yield and 31–46% for oil yield. It is interesting to note that the mean yield of the clones is slightly greater than the yield potential of 10.6 t oil ha^{-1} provided by Breure (this volume).

It is more useful to compare planting materials on the basis of oil rather than fruit bunch production, especially as costs of labour, transport and primary processing increase with time. Selection of ortet palms and field management should thus be directed to achieving a high O:B ratio. Provided that ortet palms have been selected properly, mill oil extraction rates of >24% and much greater than the national average for Malaysia of 19% can be achieved with clonal palms. Oil yields of Agrocom clones planted commercially on various soils at different sites in Malaysia consistently out-yielded D x P controls by more than 30% (range 34–57%) (Tables 4 and 5).

Table 4. Oil yields of oil palm clones planted commercially at different sites in comparison to respective D x P controls (Simon et al. (1998), Koh et al. (2001).

Soil type	Planting material	Area (ha)	25 - 36	37 - 48	49 - 60	61 - 72	73 - 84	85 - 96	97 - 108
Jawa	AGK *	9.0	2.96	5.86	7.83	8.42	9.22	10.66	-
	D x P	18.4	1.36	3.42	5.46	5.98	6.91	6.62	-
Bungor	AGK	16.2	3.00	5.67	6.69	7.04	7.15	-	-
	D x P	17.4	1.53	2.60	4.89	6.73	5.85	-	-
Bergo-song	AGK	3.4	2.46	3.57	5.94	7.24	6.15	6.88	9.31
	D x P	3.0	1.09	2.07	4.59	5.50	4.23	5.85	7.46
Inanam	AGK	15.9	1.90	1.73	5.62	11.24	9.63	5.12	-
	D x P	39.6	0.67	3.25	5.11	6.35	6.28	4.36	-
	AGK	24.2	1.62	3.97	5.86	7.21	9.48	7.44	-
	AGK	25.4	1.52	3.11	6.31	7.62	8.87	6.69	-
	AGK	25.4	1.50	4.35	5.38	6.05	10.64	8.34	-
	AGK	25.0	0.83	3.81	4.94	4.88	10.18	7.83	-
	AGK	39.0	0.62	2.69	3.92	3.93	6.67	6.44	-
Kumansi	AGK	8.8	0.95	4.04	5.34	6.29	5.80	11.31	7.94
	D x P	32.0	0.33	2.56	4.00	4.32	4.57	6.99	6.83
Merit	AGK	0.4	4.86	11.00	11.11	12.53	14.09	15.70	10.92
	D x P	56.0	1.60	3.63	5.54	7.00	6.14	7.40	6.35
Seduau	AGK	24.6	1.97	3.68	6.30	5.69	-	-	-
	D x P	124	1.45	2.92	3.32	3.54	-	-	-

**AGK = clones of Agrocom Sdn. Bhd.*

Table 5. Typical average oil extraction rate of clonal palms and D x P material (Simon et al., (1998); Koh et al., 2001).

Planting material	25 - 36	37 - 48	49 - 60	61 - 72	73 - 84	85 - 96	97 - 108
AGK	20.0	21.0	22.0	23.0	24.0	24.0	26.0
DxP	17.0	19.0	21.0	22.0	22.5	22.5	22.5

Table 6. Economics of planting oil palm clones vs. seedlings – marginal profit at various crude palm oil (CPO) and palm kernel (PK) prices.

YAP	Oil (t ha^{-1})		Marginal profit (US$ ha^{-1})		
	C[1]	S[2]	C-S[3]	C-S[4]	C-S[5]
3	2.0	1.2	137	179	242
4	4.4	2.6	308	403	545
5	6.8	4.6	376	492	666
6	8.0	5.8	376	492	666
7	9.0	6.2	479	626	847
8	9.0	6.2	479	626	847
Cumulative	-	-	2,155	2,818	3813

[1] Clone; [2] Seedling; [3] CPO = USD 184 t^{-1}, PK = USD105 t^{-1}; [4] CPO = USD 263 t^{-1}, PK = USD 131 t^{-1}; [5] CPO = USD 342 t^{-1}, PK = USD 158 t^{-1}; US$ 1 = MYR 3.8).

Oil palm clones are particularly attractive for plantations with their own milling facilities, as milling efficiency and revenues are improved by processing bunches with a high oil extraction rate. An economic evaluation using three different CPO price scenarios was made by Agrocom (1995) and has since been updated with more recent data (Table 6).

NUTRIENT REQUIREMENT OF CLONAL PALMS

As a result of the significantly higher fruit bunch and oil yields of clonal oil palms during early maturity and larger yields during the main production phase, substantial changes to the nutrient requirements can be expected during the immature and early mature phases of growth, particularly with respect to the macronutrients nitrogen (N), potassium (K) and magnesium (Mg). Woo *et al*. (1994) assessed the possible changes in nutrient dynamics based on the early growth period (≤6 YAP) and the first four years after the onset of harvesting (Table 7). Fertilizer rates were adjusted based on the results of leaf analysis and estimates of nutrient removal, in order to achieve adequate and balanced nutrition during the immature and early maturity phase.

Table 7. Cumulative oil yields and potassium requirements of clonal versus D x P palms for the first six years after planting (Woo et al., 1994).

Parameter (cummulative)	Units	Clone	DxP
Oil yield	(t ha^{-1})	32.3	19.4
Potassium application	kg	1,865	1,687
	kg K_2O ha^{-1} yr^{-1}	2.1	1.9
Nutrient use efficiency	kg oil kg^{-1} K_2O	17.32	11.50
Comparison	-	1.5	1.0

Table 8. Oil yield and nutrient requirements of clonal palms (Ng et al., 1999).

Planting material	Fertilizer * N-P-K-Mg-B	Oil yield	Oil production
	kg ha^{-1} yr^{-1}	t ha^{-1} yr^{-1}	kg oil kg^{-1} nutrients
Clones	400	8	20.0
D x P palms	360	6	16.7

* *Elemental units*

Similar calculations were made by Ng *et al*. (1999) to show the nutrient use efficiency of clonal palms (Table 8).

The greater nutrient use efficiency of clonal palms may be explained by more efficient conversion of assimilates into oil (Breure, this volume) due to the strict application of selection criteria during ortet selection (see above). Effective nutrient management becomes very important with a shift to greater oil productivity. The difference between clones and D x P material is small with respect to the total quantity of nutrients required but critical in terms of the optimal balance between nutrients (Woo *et al*., 1994; Ng *et al*., 1999). If, for example, the supply of K is not balanced with Mg, B, S and Ca, oil productivity may decrease due to the following:

- Magnesium plays an important role in the activation of enzymes involved in oil biosynthesis.
- Boron is important for successful pollination, fertilization and fruit set.
- Sulfur is a constituent of the enzyme acyl-ACP-thioesterase involved in oil formation.
- Imbalance in Ca:K:Mg ratios due to large applications of Ca (contained in phosphate rock or dolomite) may inhibit the uptake of K and Mg, suppressing bunch and oil formation.

Therefore, fertilizer treatments must be formulated to take into account the interactions between nutrients in relation to their effect on oil productivity (Table 9).

It is evident, then, that if the potential of higher oil productivity of clones is to be fully exploited, much greater emphasis must be placed on understanding the biochemical roles of the various nutrients and their interactions in relation to oil synthesis.

It may also prove useful to measure nutrient uptake and nutrient use efficiency during the first eight YAP in clonal oil palms.

Table 9. Possible impact of interactions of nutrients on oil palm productivity.

Nutrient in large supply	Nutrient in small supply	Impact on yield parameters		
		Bunch production	Oil extraction rate	Oil yield
K	Mg	+	-	-
K	B	-	-	-
S	P	-	-	-
Ca	Mg	-	-	-
Ca	K	-	-	-

\+ *positive impact, - negative impact*

CONCLUSIONS

The introduction of clonal oil palm provides palm oil producers with the opportunity to expand production by mainly improving palm productivity without the need for further area expansion (Härdter and Fairhurst, this volume). The large scale cultivation of high yielding clonal oil palm would further improve and sustain the competitiveness of palm oil *vis à vis* other vegetable oils. However, early large scale commercial introduction of clonal oil palms suffered from setbacks, mainly due to the presence of floral abnormalities in mature palms.

Recent developments in this field, however, show that it is possible to overcome these constraints by improved tissue culture protocols in the laboratory so that the percentage of mantled palms can be reduced to ≤1%. With careful selection for high-yielding ortet palms, we have shown that clones produce greater yields than conventional D x P material in terms of both fruit bunch and oil yields on a commercial scale and in a variety of different environments.

The strong emphasis on oil yield has led to the observation that clonal oil palms are not only superior converters of sunlight into carbohydrates and oil, but are also efficient in terms of nutrient use. Preliminary studies show that the quantitative nutrient demand of clones does not differ much from D x P, but there is strong indication that more attention must be paid to maintaining correct nutrient balances and ratios, and the use of suitable fertilizer sources. More research, in particular on the interaction between different nutrients and in relation to oil formation in highly productive clonal palms, needs to be undertaken.

Important points for practical planters

1 Clonal palms offer great opportunities to improve the current yields of fruit bunches and oil in oil palm.

2 When clones are planted on land with a large yield potential marginal land can be returned to forest whilst maintaining total oil output.

3 The higher yield potential of clonal palms is due to more uniform stands of highly productive individual palms, selected for large early yields, high oil extraction as well as smaller height increment growth.

4 Quality clones are characterized by low percentage of mantled (abnormal) palms (<2%).

5 Records of mature commercial plantings of over 2,000 ha have shown that clones are significantly more efficient in the utilisation of nutrients even though the total nutrient uptake may be greater than in D x P material.

6 Nutrient management for clones must focus more on correct nutrient ratios and correct application rates rather than on an overall increase in the amount of fertilizer nutrients applied.

7 Fertilizer programs must be adjusted to take account of nutrient removal in large early yields so that palms are not affected by 'hidden hunger'.

8 All macronutrients, including Ca, Mg, S and the micronutrients that play a role in oil biosynthesis must be supplied in sufficient quantity.

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